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AUTHOR(S): M. Cappiello, Q-9
J. Spore, Q-9

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COMPARISON OF TRAC-PF1/MOD1 TO A NO-FAILURE UPI TEST IN THE CYLINDRICAL CORE TEST FACILITY

by

M. W. Cappiello
J. W. Spore

ABSTRACT

TRAC-PF1/MOD1 is compared to a no-failure upper plenum injection reflood test in the Cylindrical Core Test Facility. The results show that TRAC can accurately predict the asymmetric channeling of fluid from upper plenum into the core and that a multidimensional modeling capability is required to do so. The rod temperature behavior is accurately predicted for both the peak cladding temperature and the quench time in the high- and low-power zones. Excessive downflow of liquid at the tie plate is predicted as a result of the interfacial drag model used in TRAC.

I. INTRODUCTION

As part of the International 2D/3D Program,* posttest analyses of upper plenum injection (UPI) tests in the Cylindrical Core Test Facility (CCTF) are being performed. All analyses were completed with the TRAC-PF1/MOD1 computer code (TRAC). The CCTF is operated by the Japanese Atomic Energy Research Institute (JAERI) and models a full-height core and four primary loops with scaled loop components similar to those of a pressurized water reactor (PWR). The reference plants for the design of the CCTF are the Trojan reactor in the US and the Ohi reactor in Japan. The CCTF includes 2000 electrically heated rods in the core with the capability to simulate radial and axial power distributors. The objective of the CCTF is to investigate the reflood behavior of a reactor core with various thermal and hydraulic boundary conditions representative of a large-break loss-of-coolant accident (LOCA).

Included in the objective is the investigation of the effectiveness of alternative emergency core cooling (ECC) injection methods such as UPI. The configuration of the UPI in CCTF is shown in Fig. 1. This figure shows that the UPI nozzles direct the ECC flow into the upper plenum in the radially-inward direction at the same level as the hot-leg connections. Although not shown in the figure, there exist 10 simulated control-rod guide tubes in the CCTF upper plenum. The UPI nozzles face directly towards a control-rod guide tube above the outer row

* The 2D/3D Program is a cooperative effort of the United States, Japan and the Federal Republic of Germany (FRG) to study reactor-safety aspects of pressurized water reactors (PWRs).

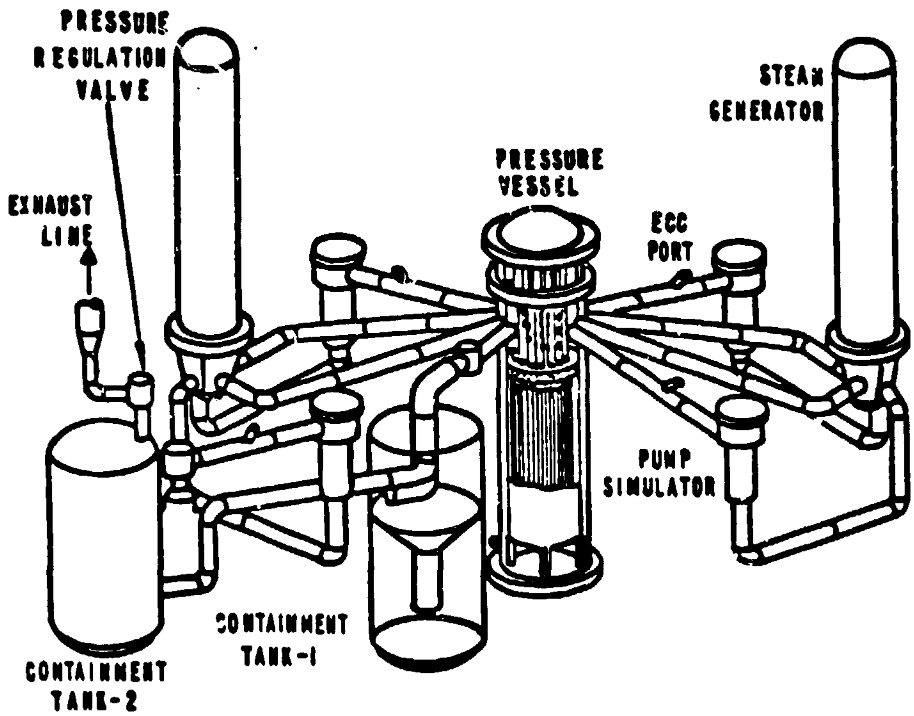

Fig. 1.
Side view of the CCTF vessel with the UPI injection into the upper plenum.

of bundles in the core. This configuration is very similar to the actual UPI method employed in several PWRs in the US.

Several UPI tests have been performed in the CCTF to study the effects of core-stored energy, ECC flowrate, and asymmetric injection.[1] The test of interest in this analysis is CCTF Run 72, which simulates a no-failure symmetric injection case with high core-stored energy.[2] Except for the high core-stored energy and peak radial power profile, this test simulates the boundary conditions that might be expected in an actual UPI PWR during a large-break LOCA. Therefore, CCTF Run 72 is an important UPI-assessment problem for reactor-safety codes such as TRAC.

TRAC is a best-estimate computer code for use in the safety analysis of PWRs. It employs a two-fluid model for the liquid and vapor phases and solves the mass, momentum and energy equations for each. Coupling between the phases is achieved through constitutive relations for the interfacial heat and momentum transfer. Wall heat transfer, friction and mass also are accounted for. Vessels and cores can be modeled in three dimensions, whereas loop components use a one-dimensional model. Core reflood during large-break LOCAs is a multi-dimensional phenomenon. This is especially true for the case of UPI injection, where local channeling of the ECC fluid from the upper plenum into the core occurs.[3] To predict accurately the dominant thermal-hydraulic phenomena during core reflood for UPI, it is necessary to use a three-dimensional analysis code such as TRAC.

II. TRAC INPUT MODEL

The TRAC input model for this calculation is shown in Figs. 2 and 3. The vessel is modeled in 3 dimensions with 4 rings, 4 azimuthal quadrants and 16 axial levels. The heated core resides in the three inner rings in levels 4 through 10. Each ring in the core represents a different power zone in the facility. Since a steep radial power profile of 1.37/1.20/0.76 was used in the test, a detailed noding is required. The upper plenum is in levels 11 through 16 with the tie plate at the top of level 12. The tie plate represents the tightest flow restriction in the axial direction between the upper plenum and the core. It is at this level, therefore, that counter current flow limitation (CCFL) is expected to occur. The hot-leg and cold-leg penetrations are at level 15 in the third and fourth rings, respectively. The UPI flow is also injected into level 15, but at two diametrically opposed quadrants. As shown in Fig. 2, the injection is into vessel cells 9 and 11.

Each of the four loops is modeled separately as shown in Fig. 3. The broken loop is similar, except that both the hot- and cold-leg sides are connected to containment tanks.

III. CALCULATIONAL RESULTS AND COMPARISON TO THE DATA

The test procedure for Run 72 was similar to most reflood experiments performed in the CCTF. The core is first allowed to heat adiabatically for 84 s. As there was no blowdown in the transient, the system was open to the containment tanks, which were held at 200 kPa. After the peak power rods reach a prescribed surface temperature of about 1008 K, the power decay is initiated and the ECC injection started. Accumulator injection into the lower plenum continued until 96 s, at which time it was switched to the cold-leg ECC nozzles. Accumulator injection to the cold legs was switched at 107.5 s to low-pressure injection (LPI). The UPI was initiated at 83.5 s and held constant throughout the transient. As this was a no-failure UPI test, the UPI was symmetrical and at a high flow rate (22 kg/s).

A pictorial rendition of the experimental flow behavior in the vessel is shown in Fig. 4. Although the UPI injection was symmetric, the data show a strong asymmetry in the quenching of the core from the top down. Specifically, the heater rods on the side of the core near the broken hot leg in the lower power zone in the quadrant directly below the UPI injector exhibit an early quenching from the top. Rods in the other quadrants do not exhibit this early quencning behavior.

A comparison of the TRAC-calculated rod temperatures to the experimental data is shown in Fig. 5 and 6. In all the data comparisons the solid lines represent the TRAC calculational results, and the dashed lines the data. Figure 5 is representative of the temperature response in the central high power zone, and Fig. 6 shows the temperature response of a rod directly under a UPI nozzle in the low-power zone on the broken-loop side of the core. Each figure shows a comparison of the calculated rod temperature to the data at three elevations: the bottom, midplane, and top of the core. As shown in the figures, the TRAC calculation is in very good agreement with the data at both locations, although TRAC does overcool the top elevation in the central power zone.

Comparisons of the ring average peak cladding temperatures (PCTs) and the times of quench are given in Table 1. As shown in the table, the overall agreement with the data is very good.

The response of the rod temperatures to the UPI through the mechanism of top quenching is not symmetric across the CCTF core. As shown in Fig. 7, TRAC is able to predict this

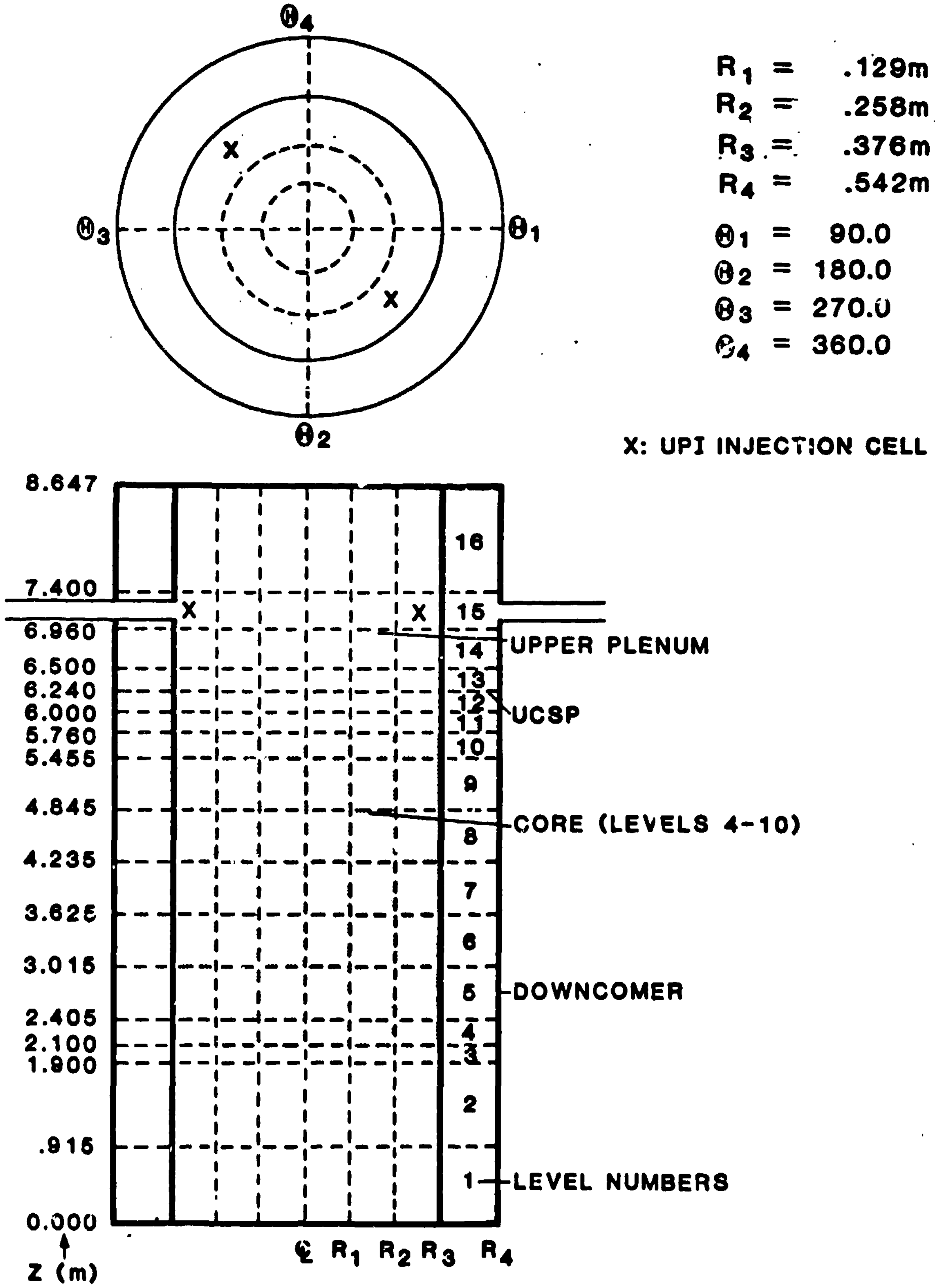

Fig. 2.
TRAC vessel noding.

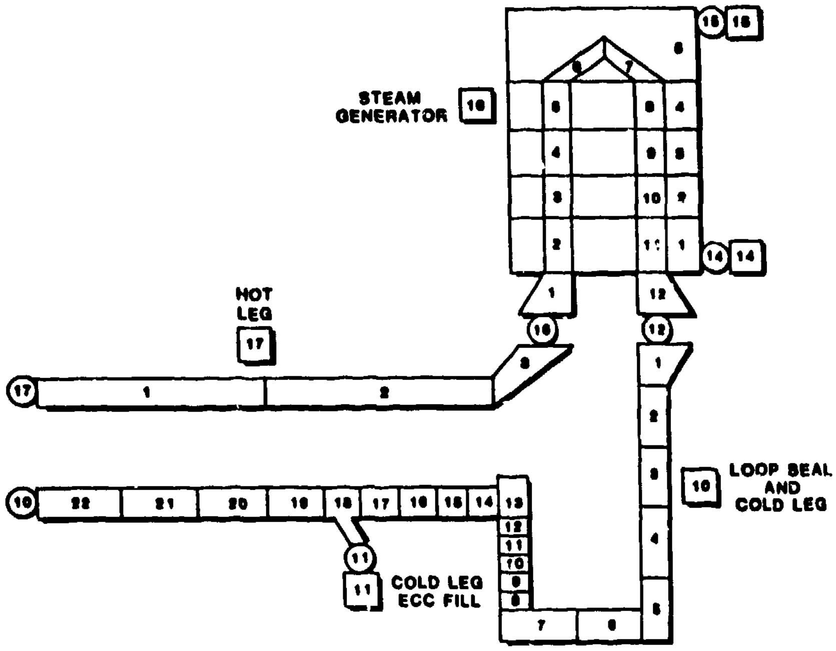

Fig. 3.
TRAC intact-loop noding.

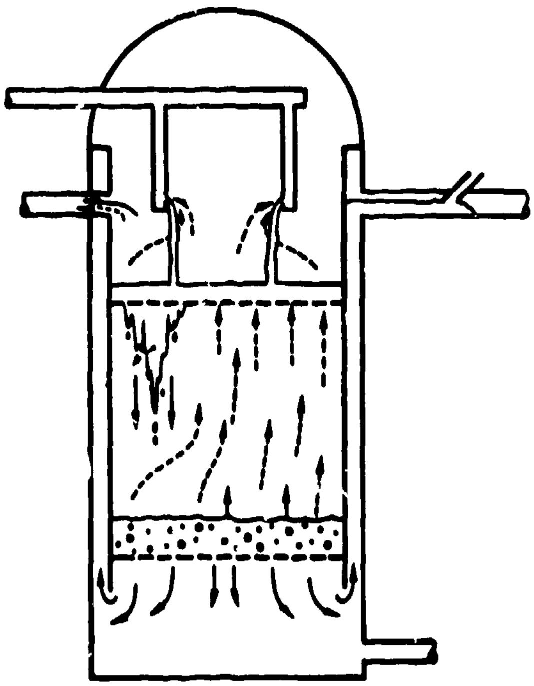

Fig. 4.
Experimental flow behavior in the vessel.

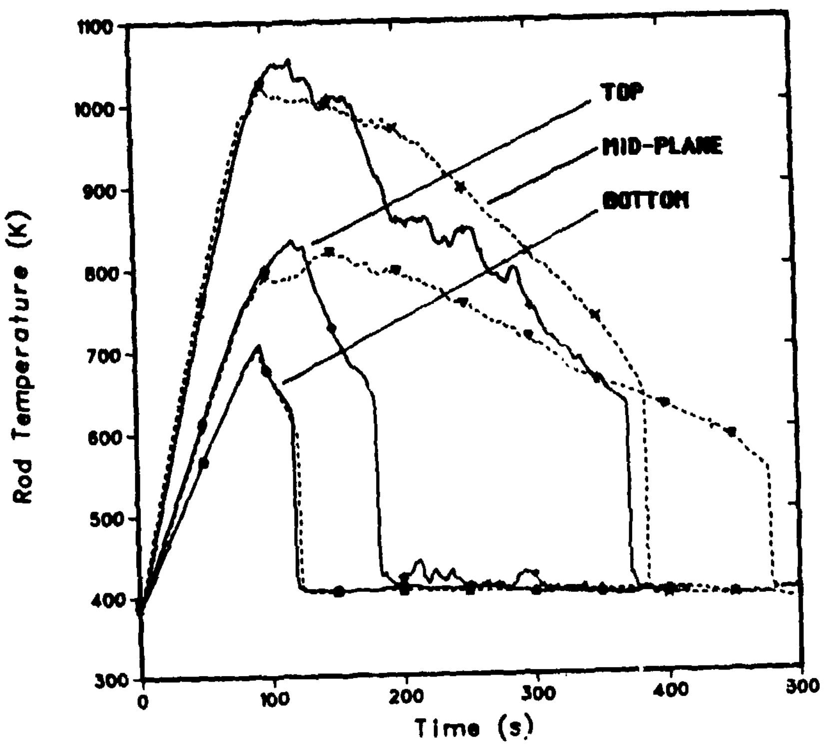

Fig. 5.
Rod-surface temperature comparison for bundle 32.

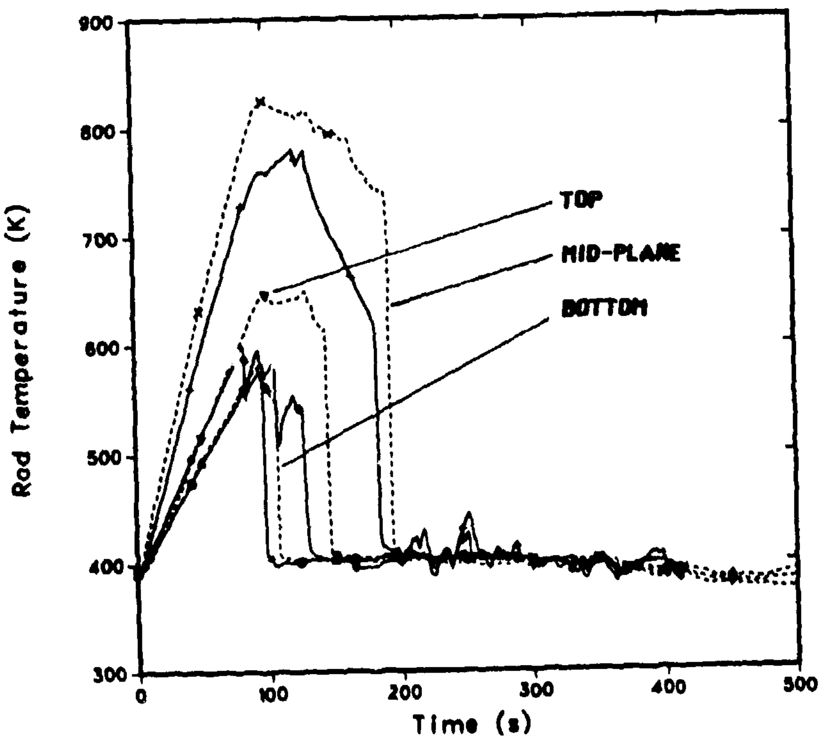

Fig. 6.
Rod-surface temperature comparison for bundle 5.

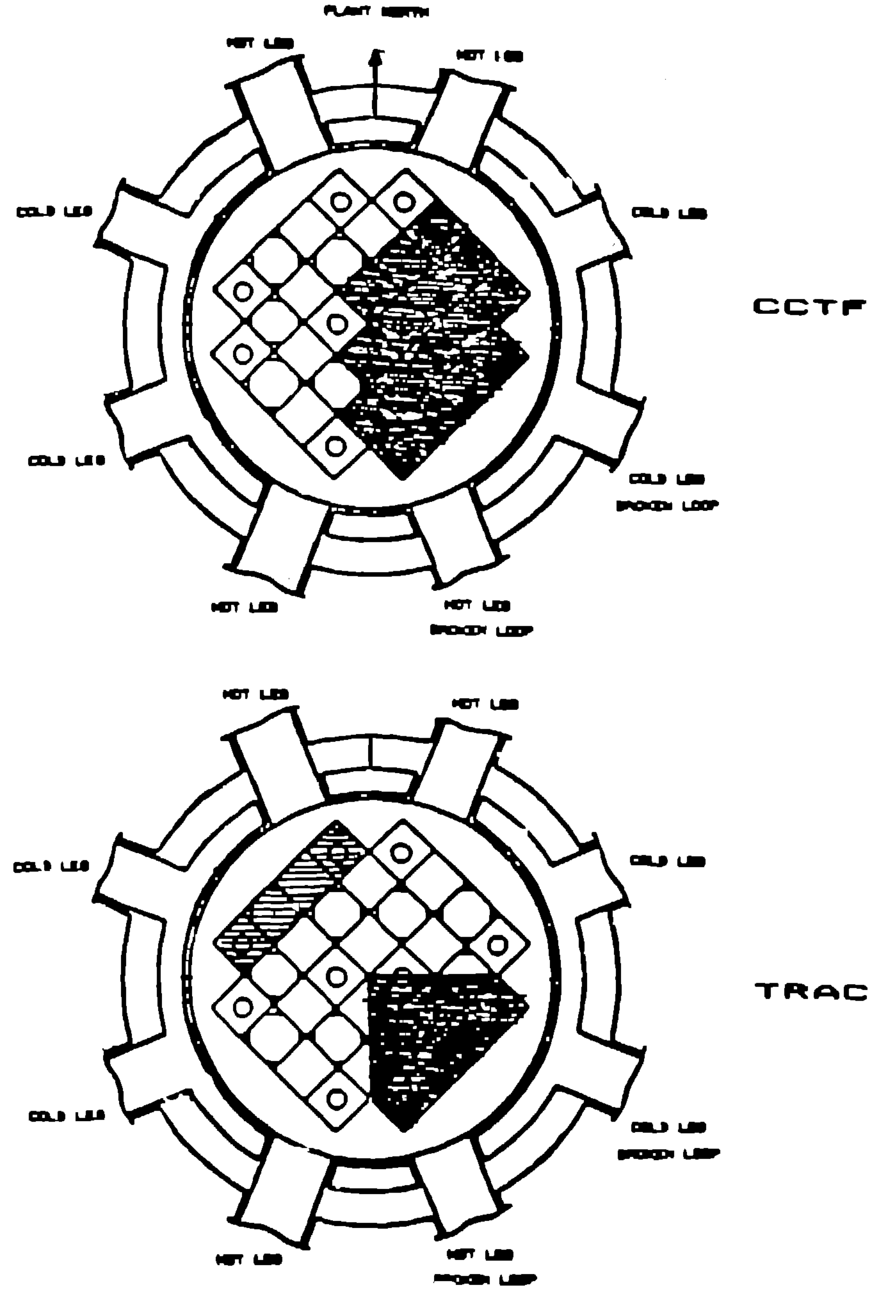

Fig. 7.
Asymmetric top quenching behavior.

TABLE I
COMPARISON OF TRAC AGAINST RING AVERAGE ROD DATA

	AVERAGE PCT(K)		AVERAGE QUENCH TIME (s)	
Ring	**TRAC**	**DATA**	**TRAC**	**DATA**
1	1057	1042	378	389
2	1030	990	380	365
3	842	806	331	300

asymmetric multidimensional behavior. Strong top quenching behavior is shown to occur in the data on only one side of the core although the UPI was symmetric. TRAC also predicts strong quenching on the same side of the core although a weaker top-quenching behavior was predicted on the opposite side of the core directly under the UPI nozzle. Both the experiment and the TRAC calculation exhibit nonsymmetrical channeling of the UPI fluid from the upper plenum to the core.

The overall core thermal-hydraulic behavior is also predicted by TRAC. The core differential pressure comparison, which is a measure of the core liquid inventory, is shown in Fig. 8. TRAC is in very good agreement with the data for the first 200 s, but tends to overpredict the liquid inventory for the remainder of the transient. The comparison of the upper plenum differential pressure is shown in Fig. 9. TRAC tends to accumulate too much fluid in the upper plenum during the first 200 s. However, at about this time a large dumping of fluid into the core occurs. The core liquid inventory is consistent with this behavior. After 200 s the upper plenum inventory increases but, as shown in the figure, never achieves the level observed in the data.

The core negative inlet flow is a unique feature of UPI-type transients. Although liquid is accumulating in the core, there is a net flow of liquid out of the core into the downcomer. This phenomenon, as shown in Fig. 10, is predicted by TRAC. The data show that approximately 15 to 17 kg/s flows out of the core, whereas TRAC shows 20 kg/s on the average. This result is consistent with the upper plenum inventory prediction because TRAC fails to accumulate as much liquid there as was shown in the data. Thus, although TRAC predicts the overall hydraulic behavior and the asymmetric channeling of flow through the core well, it tends to overpredict the amount of liquid falldown. In a separate assessment of TRAC against tie-plate CCFL data[4] for saturated conditions, it has been shown that TRAC overpredicts the downflow of falling water at a given steam upflow, although the point at which complete liquid holdup occurs is accurately predicted. Therefore, this assessment is consistent with the comparison of results for CCTF Run 72 and explains the reason for the discrepancy in the upper plenum liquid inventory and the negative core inlet flow.

IV. CONCLUSION

A comparison of TRAC to a no-failure UPI test in the CCTF has been completed. The results of this comparison lead to the following conclusions.

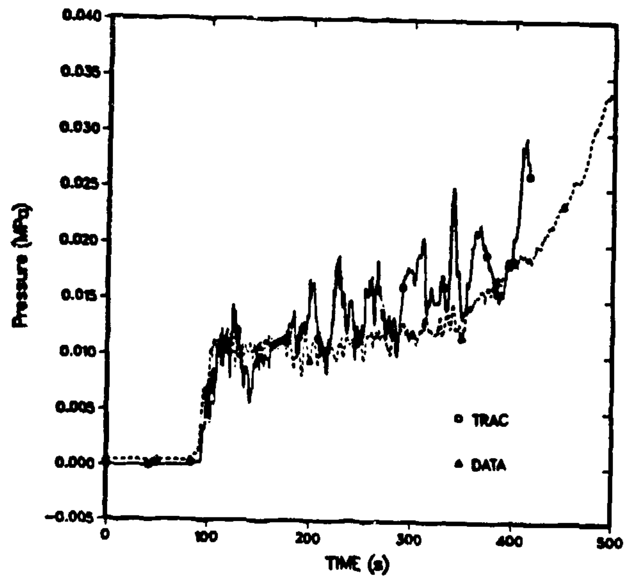

Fig. 8.
Core overall differential pressure comparison.

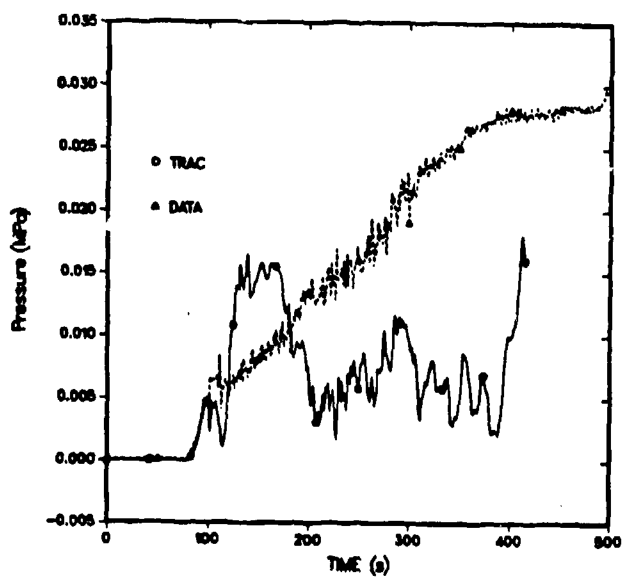

Fig. 9.
Upper plenum differential pressure comparison.

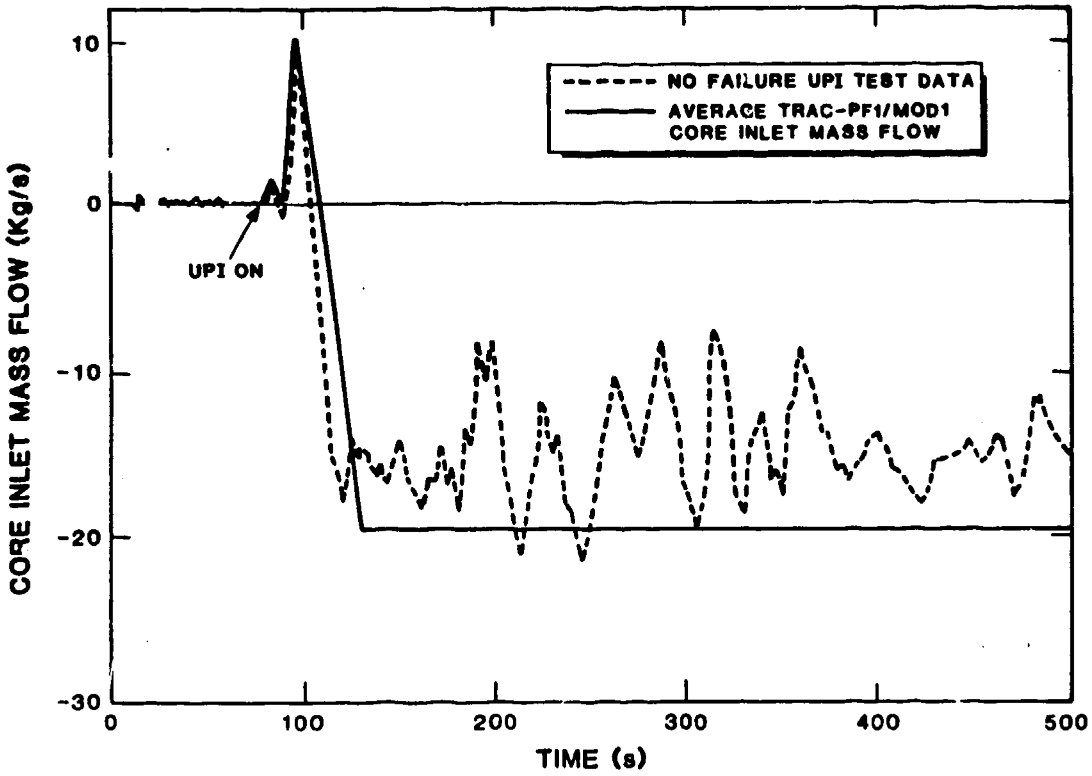

Fig. 10.
Comparison of the core inlet mass flow.

1. TRAC is able to predict the asymmetric channeling phenomenon of falling water from the upper plenum into the core. To predict this phenomenon accurately a multidimensional modeling capability such as exists in TRAC is required.
2. The overall temperature response of the rods is predicted by TRAC for both the high and low-power zones.
3. The overall core thermal-hydraulic behavior is predicted by TRAC, especially the unique result of the core negative inlet flow.
4. TRAC overpredicts the flow of falling water through the tie plate. This result is consistent with the separate-effects test assessment.

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